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A DELAY TOLERANT NETWORKING ARCHITECTURE FOR AIRBORNE NETWORKING

City University of New York, City College

April 2010

FINAL

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14. ABSTRACT
In this work we present our recent results of the novel Delay Tolerant Networking (DTN)-based probabilistic routing approach to achieve reliable communication in Airborne Networking (AN) environment associated with intermittent connectivity. The challenge is to find a routing algorithm that can deal with dynamic environment causing networks to split and merge due mainly to nodes mobility, the nature of the wireless channel jamming effect and . The new approach utilizes a DTN technique with the concept of the history of encounters to facilitate smooth information transfer between the heterogeneous nodes in Mobile Ad Hoc Network (MANET). We implement the DTN Architecture in AN environment where topology is changing rapidly because of weather, terrain, highly variable delay links, error rate links, and jamming. In our future work, the framework will include a study and analyze of the impact of the physical parameters on DTN routing protocols performance. Also, we will build a Cross Layer Design (CLD) framework that diminishes the impact of the physical layer parameters.

15. SUBJECT TERMS
Airborne Networking, Delay Tolerant Networking, routing protocols, wireless channel, cross layer design.

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1.0 SUMMARY

In this research report, we focus on enhancing the airborne networking (AN) architecture and protocols by the inclusion of the Delay Tolerant Networking (DTN) to optimize the performance of AN. We have several distinct goals for this implementation.

The first goal is design a probabilistic routing protocol to improve the end-to-end message delivery ratio in a multi-hop scenario where links are very dynamic and resources are limited. In AN environment the topology is changing rapidly because of weather, terrain, highly variable delay links, error rate links, and jamming. A key challenge is to create a method that can present good delivery performance and low end-to-end delay in an intermittent network graph and opportunistic or scheduled intermittent links where nodes may move freely. In AN environment, mobile wireless networks episodically connected because of terrain, weather, jamming, and access schedules; resulting in rapid topology changes, therefore, routing protocol will drop intermittent end-to-end connections. Delay Tolerant Networking (DTN) architecture is designed to provide communication in intermittently connected networks by moving messages towards destination via ‘store, carry and forward’ technique that supports multi-routing algorithms to acquire best path towards destination. In this proposed architecture, we will overcome this issue by implementing delay-tolerant network (DTN) architecture.

A second goal is to study and analyze the impact of the physical layer parameters and the propagation environment such as Doppler Effect, fading, etc on the performance of the DTN-based routing protocols. We build a MANET environment model using OPNET Simulator considering those physical parameters. The existing OPNET routing protocols are limited to the traditional routing protocols such as Ad hoc On Demand Distance Vector (AODV), Dynamic Source Routing (DSR) and Optimized Link State Routing (OLSR). Those protocols will fail in AN environment where the network is intermittent graph and the connection is opportunistic. The new model will be the first DTN architecture in OPNET simulator.

Our third goal is to design a cross-layer framework that uses DTN architecture to assist information exchanges between different network layers, expedites upper layers’ response to quick changes of physical links and outside environment, and helps to optimize link selections.

Our work with DTN architecture is intended to provide a multiple-purpose networking framework that can tolerate intermittent connectivity for AN environment. We evaluated the performance of our routing algorithm and compared it to common DTN based routing protocols and the performance of the protocol outperforms those common protocols. We designed the DTN-based probabilistic routing protocol to work in AN environment that is associated with intermittent connectivity. We will implement the DTN based routing algorithms in aerial and terrestrial Airborne Network environment.

2.0 INTRODUCTION

Airborne Network (AN) has to be capable of supporting the diverse Air Force (AF) missions, platforms, and communications transport needs of the future. AN environment varies from a single aircraft connected to a ground station to support voice or low speed data, to a group of hundreds of aircraft transporting high speed imagery and real-time collaborative voice and video. The objective network must be capable of forming a topology that is matched to the particular mission, platforms, and communications transport needs to optimize the performance of the network. [1]

Nodes in AN environment are capable of establishing connections with one or more other AN nodes, whether airborne, in space, or on the surface, as needed. The transmission links that used to establish the physical connections may be asymmetric with respect to bandwidth, and may be bidirectional or unidirectional. Also, the forward and reverse network connections relative to any node can take different physical paths through the network. The AN connections may be point-to-point, broadcast, or multipoint/multicast. The nodes establish connections to relay information, as needed, [1].

The AN topology is a dynamic wireless network with or without fixed infrastructure. Nodes may move freely and arrange themselves randomly. The contacts between nodes in the network do not occur very frequently. As a result, the network graph is rarely, if ever, connected and message delivery must be delay-tolerant.

The goal of this work is to provide a networking and Cross Layer Design (CLD) framework that overcomes these connectivity challenges and can be used to enhance the performance in the intermittent network environments. Although various techniques have previously been used to handle some of these issues, our goal is to develop a framework to address these challenges, and thereby leverage our development efforts for a variety of scenarios. In our framework, we will present the following contributions:

- Implementing the Delay Tolerant Networking Architecture in AN environment.
- Study the impact of the physical layer parameters on DTN routing protocols performance.
- Build a CLD framework that diminishes the impact of the physical layer.

Delay Tolerant Networking (DTN) is a newly proposed network architecture aimed at challenged network environments. DTN is an end-to-end network architecture designed to provide communication in and/or through highly stressed networking environments. Stressed networking environments include those with intermittent connectivity, large and/or variable delays, and high bit error rates. [2, 3 and 4]

3.0 METHODS, ASSUMPTIONS AND PROCEDURES

In this work, we focus on providing a framework to work in intermittent network environments. We describe the structure and design characteristics of this implementation, along with a performance analysis to demonstrate its practicality.

CLD between the physical layer and the MAC and/or the network layer has been proven to exploit networking in Mobile Ad hoc networks (MANET) which could be implemented to optimize the performance in AN such as but not limited to throughput, latency, bit error rate (BER) and packet loss ratio as we will discuss below. It is critical for AN to meet high Quality of Service (QoS) to accomplish the intended task, for example resource allocation and prioritization of traffic according to its Class of Service (CoS) (i.e. level of precedence in accordance with the commanders' operational objectives) is vital especially when resources are limited, references [5].

Our approach is built on an implementation of the DT N architecture that is a generic store-and-forward overlay network that uses medium-term storage within the network to buffer messages during link outages.

Current routing protocols favor routing traffic based on shortest path, thus causing a bottleneck. Routing in multi-hop wireless networks (such as AN) using the shortest-path metric is not a sufficient condition to construct good quality paths, because minimum hop count routing often chooses routes that have significantly less capacity than the best paths that exist in the network. Thus, it is desirable to select the routes with minimum cost based on some other metrics which are aware of the nature of the wireless underlying physical channel. In a self-organized network like airborne networking, there are many other metrics to be considered: power, packet loss, maximum available bandwidth etc., these metrics should come from CLD approach in which the network layer is aware of the state of the physical layers.

Air Force environment imposes different constraints occurring in different layers of the AN protocol stack. One CLD approach is to propagate physical layer parameters that reflects its state to the network layer, in particular Signal to Noise Ratio (SNR) that will enhance the performance of the DTN protocol in AN. The network throughput will greatly improve and average packet delay will significantly decrease. SNR experienced by mobile terminal (aircraft) is complex mobility-dependent stochastic process resulting in a fading components each of which significantly influence the performance of the wireless channel. Figure 1 presents a scenario of how our model will work to enhance the QoS.

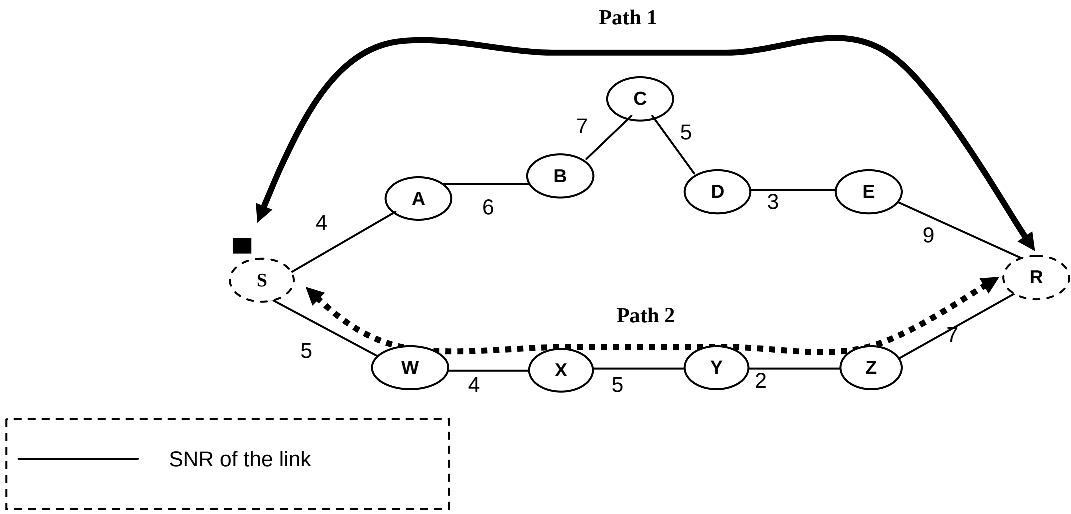

Figure 1: Scenario shows that our model will select path 1 (High QoS) rather than path 2 (minimum number of hops)

Mobility of the user affects both multi-path fading and shadowing. Multi-path fading is caused by multiple path propagation of the wave between transmitter and receiver. Shadowing is caused by loss of line of sight between transmitter and receiver due to shadowing of the propagating wave by large obstacles. While moving between shadowers, the received signal power varies in accordance with alternating interruptions and release of the line of sight between the transmitter and receiver. Therefore, with increase of mobility, the coherence time of the channel degrades due to the increase in Doppler speed.

Variable link quality effects lead to unpredictable packet errors causing loss of the packet that could be vital in the battle field. So, when the quality of the link degrades the link layer must adapt to the changes, by increasing the transmit power or using a better coding scheme. This would temporarily solve the problem if the change in SNR is due to a random fluctuation. This will cause large number of routing updates thus, increasing the routing overhead, at the transport layer the packet loss could be attributed to congestion leading to a decrease in the throughput of the network.

In this work, we have focused on enhancing the airborne networking architecture and protocols by the inclusion of CLD approach to optimize the performance of AN. This new architecture approach will improve end-to-end message delivery ratio in a multi-hop scenario where links are very dynamic and resources are limited. Furthermore, it will provide ubiquitous and guaranteed network connectivity to all Air Force platforms across dynamic heterogeneous sub-networking, with QoS assurance in mind such as minimizing BER, delay and delay variation among the aircrafts in the AN.

In our model to design a DTN routing protocol (goal 1) we used the Opportunistic Network Environment (ONE-V1.0) simulator to build up our scenario. For our simulation, we used the simulation setup that used in table 1. We ran our simulation with numbers of nodes starting with 5 nodes till 200 nodes in area of 4500 x 3400 m. We use several different types of speeds of 1.5 m/s (Pedestrians), 15 m/s (cars), 10 m/s (trams). We assume buffer size of 5 Mbyte for each node. [6, 7].

Table 1. Simulation Parameters

SIMULATION ENVIRONMENT PARAMETERS	VALUE
Simulation Area (W x H) meter	4500 x 3400
Simulation duration (hr)	12
Number of nodes	5 -200
Movement Model	Shortest Path Map Based Movement
Message TTL (Seconds)	60
Host speed (m/s)	1.5 -15
Buffer size (Mbyte)	5

4.0 RESULTS AND DISCUSSION

Figures 2 through 7 below show some results obtained in the simulation. The results presented are an average of runs of each scenario by changing number of nodes and buffer size. Our new DTN routing protocol is called History of Encounters Probabilistic Routing Algorithm (HEPRA). We compared the new approach, HEPRA to the common DTN-based protocols, Epidemic and PROPHET protocols. We demonstrate the ability of HEPRA to accomplish good quality performance than the other common existing Protocols. HEPRA increased the delivery rate, decreased the latency and overhead ratio than other protocols.

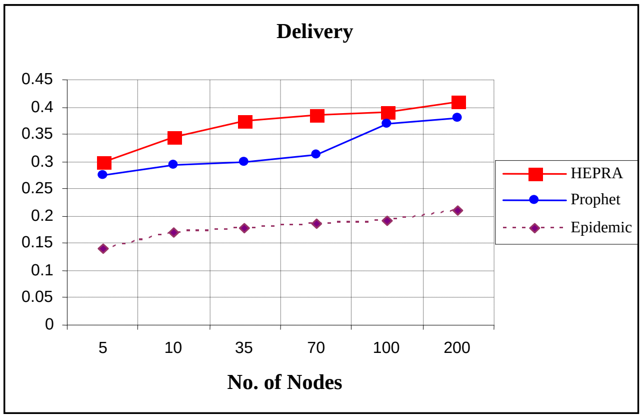

Figure 2. HEPRA increases delivery when number of nodes increases

Figure 5. HEPRA increases delivery when size of buffer increases

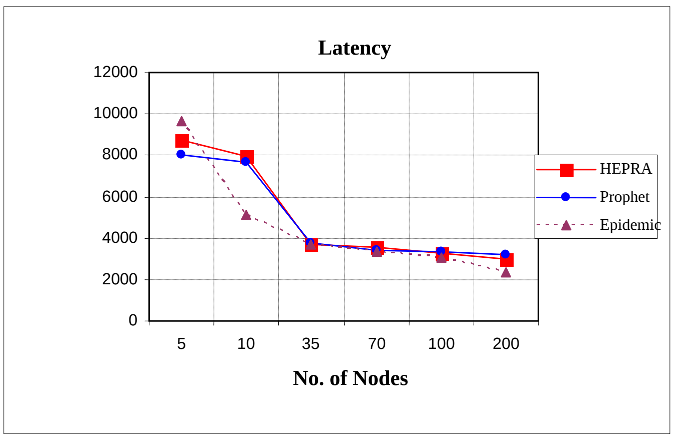

Figure 3. HEPRA reduces latency when number of nodes increases

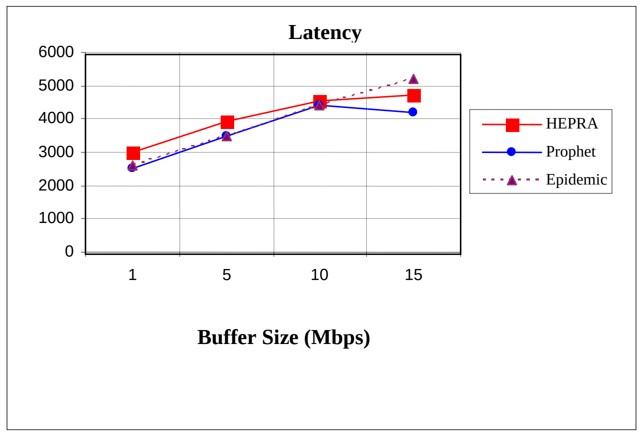

Figure 6. HEPRA reduces latency when size of buffer increases

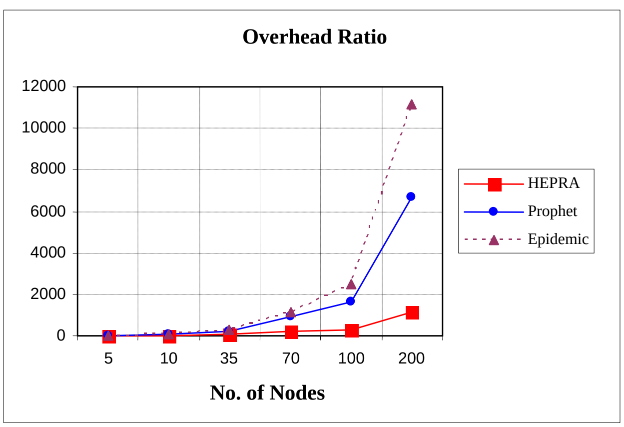

Figure 4. HEPRA reduces overhead (OH) Ratio when number of nodes increases

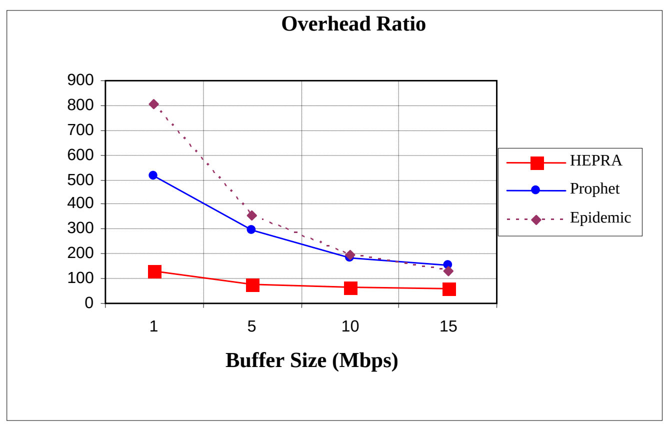

Figure 7. HEPRA reduces OH Ratio when size of buffer increases

5.0 CONCLUSION

We present our recent results of the novel DTN-based probabilistic routing approach to achieve reliable communication in networks associated with intermittent connectivity. The challenge was to find a routing algorithm that can deal with dynamic environment causing networks to split and merge due to nodes mobility, nature of the wireless channel, and jamming effect. The new approach utilizes a DTN technique with the concept of the history of encounters to facilitate smooth information transfer between the heterogeneous nodes in Mobile Ad Hoc Network. We designed our approach using a novel History of Encounters Probabilistic Routing Algorithm: HEPRA. Simulation results show that HEPRA achieved better performance than other common DTN based protocols in terms of delivery rate, overhead ratio and average number of hopcounts over intermittent network. Also, HEPRA performance was consistent with changing number of nodes and nodes' buffer sizes.

We intend to continue on developing the proposed algorithm and provide a detailed analytical as well as simulation-based study. Our future work will complete the research to achieve the followings: 1) implement DTN based routing algorithms such as HEPRA in Aerial/terrestrial Airborne Network environment. 2) we will study and analyze the impact of the physical layer parameters on the performance of the DTN-based probabilistic routing protocols such as HEPRA, epidemic, etc. 3) we will design a cross-layer frame assists information exchanges between different network layers, expedites upper layers' response to quick changes of physical links and outside environment, and helps to optimize link selections.

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7.0 LIST OF SYMBOLS, ABBREVIATIONS, AND ACRONYMS

AF	Air Force
AN	Airborne Networking
AODV	Ad hoc On Demand Distance Vector
BER	Bit Error Rate
CLD	Cross Layer Design
CoS	Class of Service
DSR	Dynamic Source Routing
DTN	Delay Tolerant Networking
HEPRA	History of Encounters Probabilistic Routing Algorithm
MANET	Mobile Ad Hoc Network
OH	Overhead
OLSR	Optimized Link State Routing
ONE	Opportunistic Network Environment
QoS	Quality of Service
SNR	Signal to Noise Ratio

APPENDIX

Published Papers

1. F. Alnajjar, T. Saadawi, "HEPRA: History of Encounters Probabilistic Routing Algorithm in Delay-Tolerant Network" The Ninth IASTED International Conference on Parallel and Distributed Computing and Networks, Innsbruck, Austria, 2010.

2. N. Pradhan and T. Saadawi, "Topology Control Using Distributed Power Management Algorithm in Mobile Ad Hoc Networks," 17th International Conference on Software Telecommunications and Computer Networks, SoftCOM 2009, Split-Hvar-Korcula, September 2009.

HEPRA: HISTORY OF ENCOUNTERS PROBABILISTIC ROUTING ALGORITHM IN DELAY-TOLERANT NETWORK

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ABSTRACT
Routing in mobile ad hoc networks (MANET) is complex and complicated because the network graph is episodically connected. The topology is changing rapidly because of weather, terrain, highly variable delay links, error rate links, and jamming. A key challenge is to create a method that can present good delivery performance and low end-to-end delay in an intermittent network graph and opportunistic or scheduled intermittent links where nodes may move freely. Delay-Tolerant Networking (DTN) architecture is designed to provide communication in intermittently connected networks by moving messages towards destination via 'store, carry and forward' technique that supports multi-routing algorithms to acquire best path towards destination. In this paper, we propose the use of probabilistic routing in DTN architecture using the concept of History of Encounters. We compared the new approach, History of Encounters Probabilistic Routing Algorithm (HEPRA) to the common DTN-based protocols. We have used the Opportunistic Network Environment (ONE) simulator as a simulation tool. We demonstrate the ability of HEPRA to accomplish good quality performance than the other common existing Protocols.

KEYWORDS
DTN, MANET, Probabilistic routing protocol

1. Introduction

Delay Tolerant Networking (DTN) is an end-to-end network architecture designed to provide communication in and/or through highly stressed networking environments. Stressed networking environments include those with intermittent connectivity, large and/or variable delays, and high bit error rates. The DTN Research Group (DTNRG) leads the field in DTN research. Members of the DTNRG created the Bundle Protocol (BP) to implement the DTN architecture. The key capabilities of the bundle protocols include custody-based reliability, ability to cope with intermittent connectivity, ability to take advantage of scheduled and opportunistic connectivity, and late binding of names to addresses [1], [2] and [3].

As an effort to standardize communications for the Interplanetary Internet (IPN), the Delay-Tolerant Networking architecture and protocols were proposed. ('DTN architecture and protocols were proposed as an effort to standardize communications for the IPN'). As work progressed, researchers observed that military networks running tactical protocols, and remote networks where network resources are scarce and data mules might be used to transport data. These networks all had similarities in that they experienced several of these features: asymmetric communication, noisy links, long delays, and intermittent connectivity. As a result, the network community is developing a body of research for which funding has been established by both NASA and DARPA.

The network architecture and protocol design process involves analysis and implementation of the protocols, validation of their behaviors and performance evaluation [8], [9].

A Mobile Ad hoc Network (MANET) is a dynamic wireless network with or without fixed infrastructure. Nodes may move freely and arrange themselves randomly. The contacts between nodes in the network do not occur very frequently. As a result, the network graph is rarely, if ever, connected and message delivery must be delay-tolerant.

Traditional MANET routing protocols such as DSR, AODV and OLSR requires that the network graph is fully connected and fail to route messages if there is not a complete route from source to destination at the time of sending. For this reason traditional ad hoc routing protocols cannot be used in environments with intermittent connectivity. [3].

To defeat this issue, node mobility is exploited to physically carry messages between disconnected parts of the network. Schemes like these designs are occasionally referred to as Mobility Assisted Routing (MAR) that employs the store, carry and-forward model.

Mobility-assisted routing comprises each node separately making forwarding decisions that occur when two nodes meet. A message gets forwarded to encountered nodes until it reaches its destination.

Messages may have to be buffered for a long time by intermediate nodes, and the mobility of those nodes must be utilized to bring messages closer to their destination by exchanging messages between nodes as they encounter. [4].

Figure 1 shows how the mobility of nodes in such circumstances can be employed to ultimately deliver a message to its destination. In this figure, node A has a message (indicated by the node being sky blue) to be delivered to node F, but a path does not exist between nodes A and F. As shown in figures (a-d), the mobility of the nodes let the message be transferred to node B (fig b), then to node E (fig c), and finally, when node E moves within range of node F to node F which is its final destination.[6],[10].

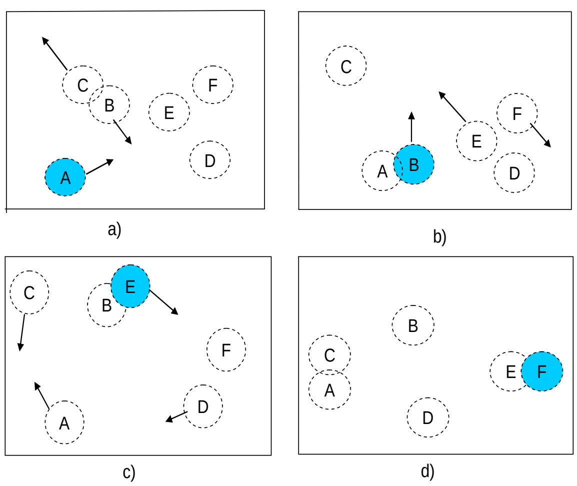

Figure 1. A message (shown in the figure by the node carrying the message being sky blue) is moved from node A to node F via nodes B and E utilizing the mobility of nodes [6]

In this paper we discuss the routing in networks associated with intermittent connection. We present our probabilistic routing algorithm by utilizing the concept of history of encounter to deliver messages to their destinations. We demonstrate two common DTN based routing protocols, Epidemic and PROPHET routing protocols [5],[6] comparing them to our results. We have used in our simulation the Opportunistic Network Environment simulator ONE-V1.0. [7]

This paper is organized as follows:

Section 2 describes some related work
Section 3, shows our proposed model
Section 4 shows the simulation setup
Section 5 summarizes the results of simulations
Section 6 discusses our conclusion
Section 7 presents future work

2. Related Work

DTN overcome the problems associated with intermittent connectivity, long or variable delay by using 'store, carry and forward' message switching.[4],[11]. Existing DTN-based- Routing protocols are classified by routing protocols that replicate packets and those that forward only a single copy [9]. By moving entire messages (or fragments thereof) in a single transfer, the message-switching procedure provides the nodes in the network with immediate knowledge of the size of messages, and therefore the requirements for intermediate storage space and retransmission bandwidth [3], [4]. In this paper we select two common DTN-based protocols Epidemic Routing protocol and PROPHET routing protocol. We compared our new approach to Epidemic and PROPHET to demonstrate the ability to accomplish good quality performance.

2.1 Epidemic Routing

Vahdat and Becker [5] present a routing protocol for networks associated with intermittent connectivity called Epidemic Routing protocol. Epidemic utilized the theory of epidemic algorithm to ultimately deliver messages to their destination when nodes encounter each other by doing random pair-wise information of messages between the encountered nodes. If bath to destination is not accessible, the node will buffer the messages in index called summary vector. Each node maintains a buffer consisting of messages that it has originated in addition to messages that it is buffering on behalf of other hosts.

Once two nodes meet they exchange the summary vectors. If the node finds any unseen messages, it requests them from the encountered node. This mechanism of swapping new messages continues as long as buffer space is available, and messages will spread similar to an epidemic of some diseases inside the network whenever infected node meets susceptible node, a copy is forwarded (flooding), see figure 2. In order to avoid duplicate messages during the exchange process each message has a globally unique message ID. Each message contains source and destination addresses. Also, to lower the utilization of nodes resources, each message has a hop counter to determine the maximum number of hops a message can travel to. Epidemic depends on two factors; buffer size and maximum hop count that those items control the performance of the scheme.

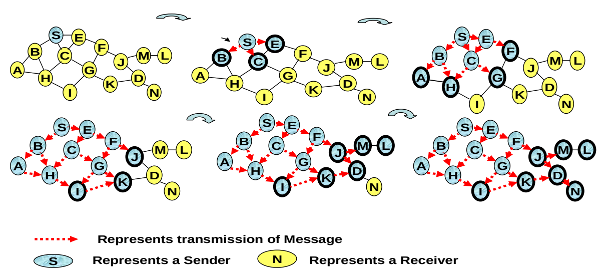

Figure 2. Epidemic Routing Protocol: Epidemic uses flooding to transfer messages to destination [5]

2.2 PRoPHET Routing

Anders Lindgren and et al [6] present a Probabilistic routing algorithm called PROPHET. It stands for Probabilistic ROuting Protocol using History of Encounters and Transitivity. Authors established a probabilistic metric called delivery predictability $P_{(a,b)} \in [0,1]$ at every node a for each known destination b.

The procedure of PROPHET is like the Epidemic Routing, in which, two nodes exchange summary vectors when they meet. In addition to that, in PROPHET, it contains the delivery predictability information stored at the nodes. This information is used to update the internal delivery predictability vector and then the information in the summary vector is used to decide which messages to request from the other node. The forwarding strategy depends on the delivery predictability of the encountered nodes. If node a meets node b, a carried message destined for node m will be transferred from a to b only if $P_{(b,m)} > P_{(a,m)}$.

PROPHET algorithm relies on calculation of delivery predictability to forward messages to the reliable node. The probability is used to decide if one node is more reliable than the other to forward message to the destination node. It includes three parts about the probability.

First is to update the probability metric whenever a node is encountered, the node that is frequently encountered having higher delivery predictability than others. Second, if a pair of nodes do not encounter each others during an interval, they are less likely to be good forwarders of messages to each other, thus the delivery predictability values must be reduced. Third, there is a transitive property in delivery predictability. Based on the observation, if node a frequently encounters node b, and node b frequently encounters node c, then node c probably is a good node to forward messages destined for node a.

3. Propose Work

Delay tolerant networks have been proposed to address data intermittent communication challenges in networks where an instantaneous end-to-end path between a source and destination may not exist, and the links between nodes may be opportunistic, predictably connectable, or periodically-(dis)connected [9].

In this research proposal, we focus on the Delay-Tolerant Mobile Ad Hoc Network to design a probabilistic routing protocol applicable to work in this intermittently connected environment to improve the end-to-end message delivery ratio in a multihop scenario where link availability can be low. We have designed our algorithm to 1) maximize message delivery rate, 2) minimize the total resources consumed in message delivery, 3) minimize the number of hops used in routing and 4) minimize message latency.

In the environment of periodically disconnected, nodes get only episodically connected because of terrain, weather, and jamming that change topology rapidly. As explained in Section 2, Epidemic routing protocol solves this issue by epidemically spreading the information through the network and PROPHET routing protocol solves it by applying some knowledge of the mobility of nodes to forward messages based on probabilistic factors. [5], [6].

Our improved routing algorithm will overcome the problem of periodically-disconnected network by applying the factor of history on encountered of each node for forwarding strategy. We employed the concept of history of encountered that used to forward messages to encountered nodes. Messages will be transferred towards destination via ‘store, carry and forward’ technique that is used in DTN based routing protocols. Our new approach is called History of Encounters Probabilistic Routing Algorithm (HEPRA).

The operation of HEPRA relies on the knowledge of the mobility of nodes to forward messages based on encountered nodes in the past. We determine the History of encounters probabilistic factor of any node based on how many nodes did this node encounter until the moment of meeting a new node. If node a meets node b and the History of encounters probabilistic factor of node a is greater than node b, so it means that node a encountered more nodes than node b until the encountering time. In this case, node a will not forward any messages to node b but will do. HEPRA uses the history of encountered nodes to predict its future suitability to deliver messages to next node toward destination. An index of encountered nodes called a summary vector is kept by each node. Each Node maintains the summary vector that lists all encountered nodes during its mobility. The buffer size of each node controls the size of the summary vector.

When two nodes meet, they update the summary vector. Then, they exchange summary vectors which in this case also contains the list of encountered nodes stored at the nodes. This information in the summary vector is used to decide which messages to request from the other node based on the History of encounters factor used in the forwarding strategy.

Our forwarding strategy depends on the History of encounters of nodes in the network. We create a metric called History of encounters at every node. This indicates how highly-encountered the node is, which the number of nodes encountered till that moment is. The calculation of messages delivery depends on the History of encounters metric. When two nodes meet, the first thing to do is to update the metric (increase the metric by one), then they swap the number of encountered nodes till moment of meeting so that nodes that are often encountered more nodes have a high delivery Probability. Encountered nodes exchange only the number of earlier contacts without any details of those nodes. If they met the same number of nodes in the past they exchange new messages and if one of them encountered more nodes than the other in the past, only the node with low number of earlier contacts will deliver the new messages to the node with high earlier contacts. When a message arrives at a node, there might not be a path to the destination available so the node has to buffer the message. Upon each encounter with another node, a decision must be made on whether or not to transfer that particular message.

Our Mathematical model is based on the probability of an event equals the ratio of its favorable outcomes to the total number of outcomes provided that all outcomes are equally likely. According to the classical definition, the probability P(A) of an event A is determined a priori without actual experimentation: It is given by the ratio $P(A)=\frac{N_A}{N}$ where N is the number of possible outcomes and N_A is the number of outcomes that are favorable to the event A. In HEPRA, when node a ,encountered 8 nodes carries messages to deliver to final destinations, meets node b ,encountered 5 nodes, node a will not forward any messages to node b since $P(a)\left(=\frac{N_a}{N}\right) > P(b)\left(=\frac{N_b}{N}\right)$. We will forward messages from a node to another only if the probability of the encountered node is greater than the node that carried messages.

The flow chart in figure 3 demonstrates the mechanism of how HEPRA is working to deliver messages towards final destination. When node i meets node j they update the summary vector. Then, they exchange the summary vector. Each node will check the History of Encounters metric of each other. If the history of encounters metric of node i is less than node j, node i will transfer any unseen messages to j but not vice versa. Node i will deliver messages to destinations if path to destination available, otherwise, it will store the messages in the buffer and continue mobility till encountering new node. Employing the concept of s history of encounters factor increases the probability of delivering messages to intermediate nodes and destinations since the probability of delivering messages by highly encountered - connected nodes is higher than lower encountered connected nodes.

HEPRA utilizes information about the earlier contacts to predict how good nominee a node is to deliver the message to the recipient. In HEPRA, messages carried by the node with a higher probability, based on the history of encounters condition, only are transferred.

Our research results show that HEPRA can deliver more messages than PROPHET and Epidemic with lower number of hops.

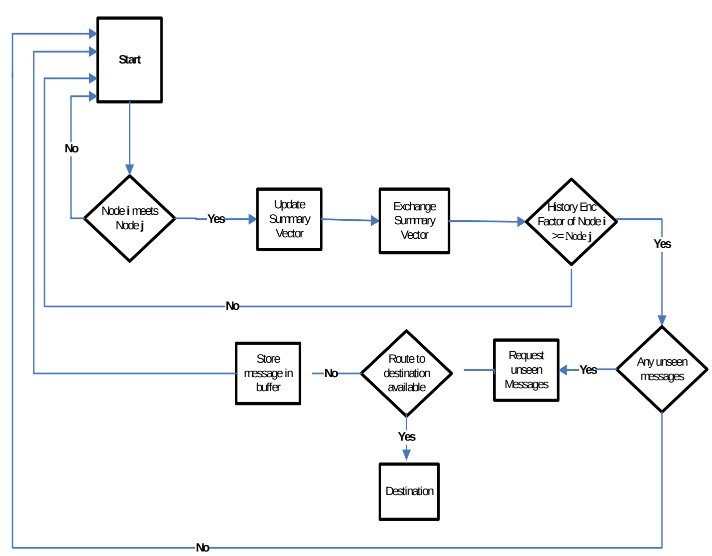

Fig.3. How the mechanism of message delivery is working in HEPRA algorithm

4. Our Model & Simulation Setup

Ari Keranen and Jorg Ott [7] presented the Opportunistic Network Environment simulator (ONE-V1.0) which provides a powerful tool for generating mobility traces, running DTN messaging simulations with different routing protocols, and visualizing simulations interactively in real-time and results after their completion. We used ONE-V1.0 in our simulation.
Figure 4 shows a screenshot of ONE simulator.

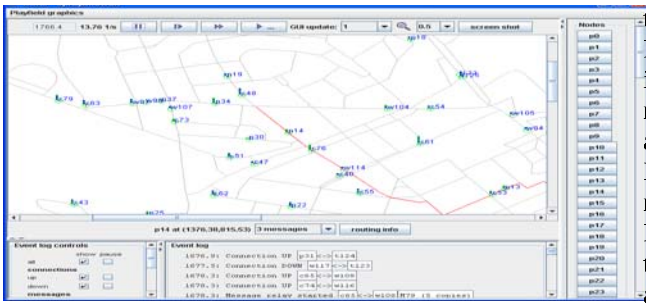

Fig.4. Simulator ONE Screenshot

For our simulation, we used the simulation setup that used in [7]. Table 1 shows the parameters used in our simulation. We ran our simulation with numbers of nodes starting with 20 nodes till 600 nodes in area of 4500 x 3400 m. We use several different types of speeds of 1.5 m/s (Pedestrians), 15 m/s (cars), 10 m/s (trams). We assume buffer size of 5 Mbyte for each node.

Table1
Simulation setup parameters

SIMULATION ENVIRONMENT PARAMETERS	VALUE
Simulation Area (W x H) meter	4500 x 3400
Simulation duration (hr)	12
Number of nodes	5 -200
Movement Model	Shortest Path Map Based Movement
Message TTL (Seconds)	60
Host speed (m/s)	1.5 -15
Buffer size (Mbyte)	5

5. Results

The results presented in figures 5 and 6 are an average of 10 runs of each scenario by changing number of nodes and buffer size. The buffer size was set to 5 Mbyte in figures 5.1–5.5.

It is immediately evident from the results given in Figure 5.1 that our algorithm, HEPRA, outperforms Epidemic and PROPHET in terms of message delivery with increasing number of nodes. This is because HEPRA forward messages to highly connected nodes that meet nodes continually that guaranteed the message delivery.
Figure 5.2 shows that the overhead ratio of HEPRA is lower than the other algorithms with increasing number of nodes. Epidemic sends the messages to all nodes that make the overhead ratio number high.
Figure 5.3 shows that HEPRA use less average number of hopcounts to reach destination than Epidemic and PROPHET. HEPRA send messages to only highly connected nodes that will reduce the average hopcount number.
Figure 5.4 shows that Epidemic performs better than HEPRA and PROPHET in terms of latency with increasing number of nodes. But HEPRA performs similar to Epidemic with middle size network. This is normal in HEPRA case since it gives messages to only highly connected nodes which increase the latency.
Figure 5.5 shows that PROPHET buffers messages in time less than the others. The last result explains that HEPRA needs time to buffer messages since it forward messages to only certain nodes that are have high number of history of encounters connected and sorting required time for this process.

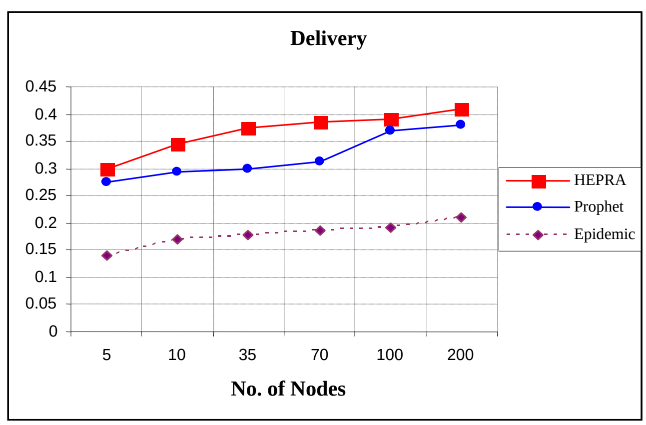

Fig.5.1. HEPRA delivers more messages than PROPHET and Epidemic

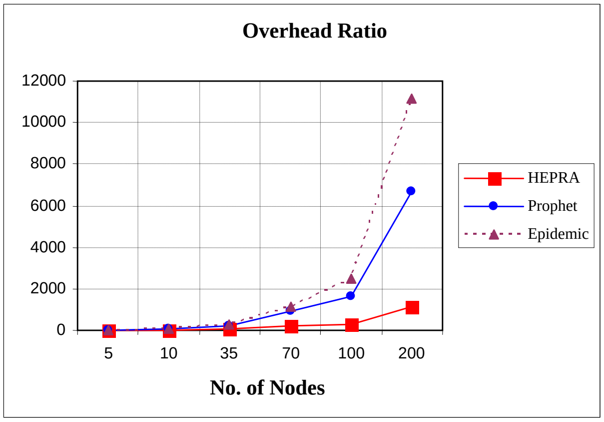

Fig.5.2. HEPRA reduces the overhead ratio

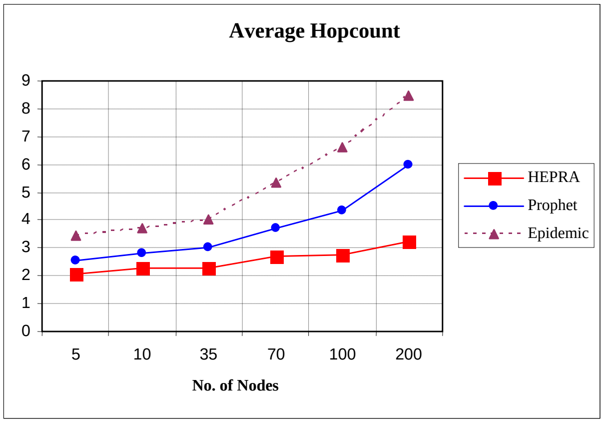

Fig.5.3. Number of Hops in HEPRA is lower than others

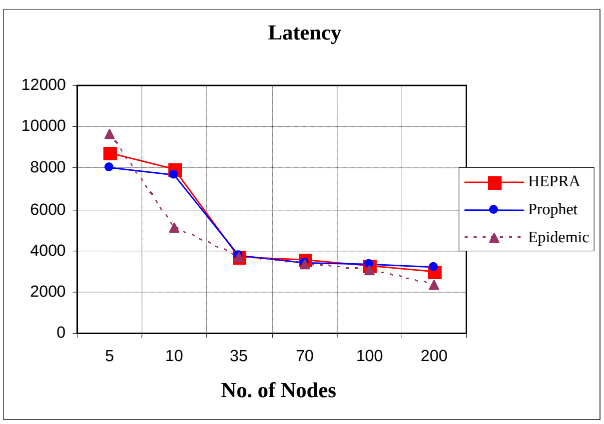

Fig.5.4. Delay in HEPRA is acceptable

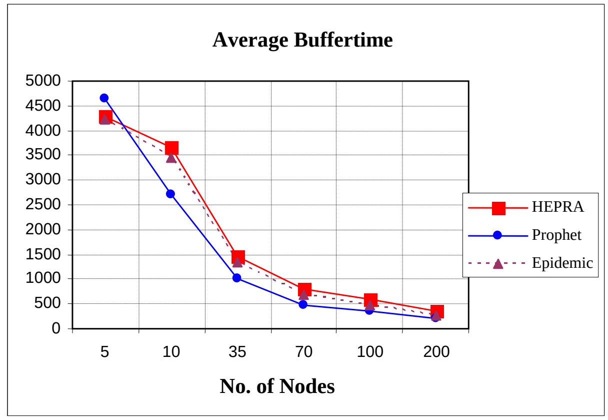

Fig.5.5. The buffer time in HEPRA and Epidemic is higher than PROPHET

Figures 6.1 – 6.5 show results after we fixed the number of nodes to 40 nodes and changed buffer size from 1 Mbyte to 15 Mbyte. The obtained results are similar results obtained in figures 5(1-5). HEPRA outperforms Epidemic and PROPHET in terms of delivery probability, overhead ratio and average number of hopcounts. Whereas Epidemic performs better in terms of latency and PROPHET presents better performance in buffer time.

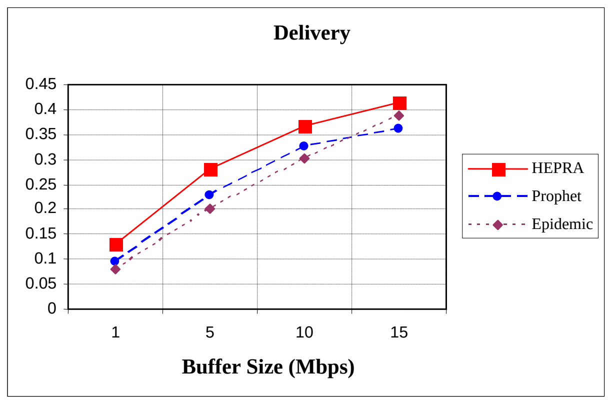

Fig.6.1. HEPRA delivers more messages than PROPHET and Epidemic

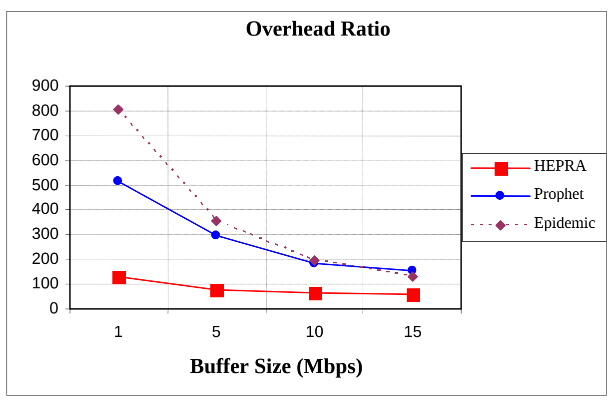

Fig.6.2. HEPRA reduces the overhead ratio

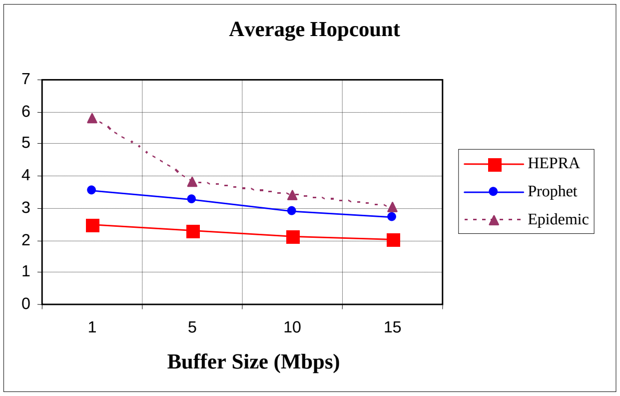

Fig.6.3. Number of Hops in HEPRA is lower than others

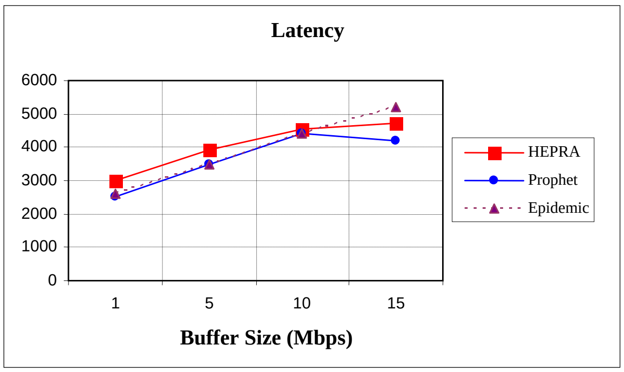

Fig.6.4. Delay in HEPRA is acceptable

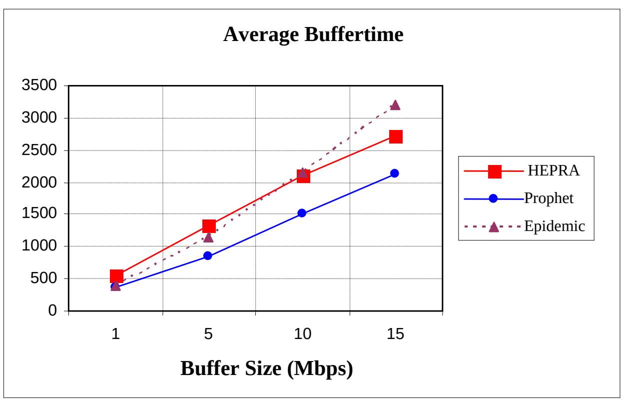

Fig.6.5. The buffer time in HEPRA and Epidemic is higher than PROPHET

6. Discussion and Conclusion

In this paper, we have presented our recent results of the novel DTN-based probabilistic routing approach to achieve reliable communication in networks associated with intermittent connectivity. The challenge was to find a routing algorithm that can deal with dynamic environment causing networks to split and merge, considering nodes mobility. The new approach utilizes a DTN technique with the concept of the history of encounters to facilitate smooth information transfer between the heterogeneous nodes in Mobile Ad Hoc Network. We designed our approach using a novel History of Encounters Probabilistic Routing Algorithm: HEPRA. Simulation results show that HEPRA achieved better performance than other common DTN based protocols in terms of delivery rate, overhead ratio and average number of hopcounts over intermittent network. Also, HEPRA performance was consistent with changing number of nodes and nodes' buffer sizes.

7. Future Work

We intend to continue on developing the proposed algorithm and provide a detailed analytical as well as simulation-based study. Our future work will complete the research to achieve the followings: 1) implement DTN based routing algorithms such as HEPRA in Aerial/terrestrial Airborne Network environment. 2) we will study and analyze the impact of the physical layer parameters on the performance of the DTN-based probabilistic routing protocols such as HEPRA, epidemic, etc. 3) we will design a cross-layer frame assists information exchanges between different network layers, expedites upper layers' response to quick changes of physical links and outside environment, and helps to optimize link selections.

Acknowledgements

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Topology Control Using Distributed Power Management Algorithm for Mobile Ad Hoc Networks

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Abstract- **We propose a distributed power management algorithm that decides on an optimum coverage area for individual node to preserve network connectivity, reduce interference thus improve network performance with changing environment and network topology. In order to be strongly connected in the network, a node may increase its power indiscriminately causing interference. Since interference is one of the major problems in wireless network, the proposed algorithm will co-operatively reduce inter-node interference in the network. Uni-directional links are also a major source of interference as most of the routing protocol only utilizes bi-directional links. So, the algorithm will attempt to prevent such links or if required convert them into bi-directional links.**

We will show that the algorithm provides strongly connected and more reliable network over dynamic physical channel modeled by log-distance path loss model, log-normal shadowing model and rayleigh fading model. We will show that the proposed algorithm stabilizes node connectivity over the dynamic network and environment and even, to a certain extent, prevent node from being completely disconnected from the network. Further, it reduces interference and improves network performance.

***Index Terms*–** **Mobile ad hoc networks, distributed power management algorithm, routing protocol, interference, uni-directional link, bi-directional link, physical propagation model.**

1. INTRODUCTION

The topology of a network and the performance of routing protocol in mobile ad hoc networks significantly deteriorate with the dynamic attenuating environment [1]. The coverage area of a node or the propagation distance of the signal is limited by propagation loss and fading losses due to reflection, diffraction, scattering and multipath. These losses are estimated by propagation models. We will model the propagation loss by log-distance path loss model, the random shadowing effects by log-normally distributed fading loss and small-fading loss and the doppler effect by rayleigh fading model. Thus, the propagation environment determines the coverage area of a node and its connectivity.

These propagation and fading losses determine the Signal to Noise Ratio (SNR) and the Bit Error Rate (BER) of a communication link. In reality, multi-user networks are interference-limited rather than noise-limited. Interference from other nodes in the network can be more significant than background noise. Therefore, we will consider Signal to Interference and Noise Ratio (SINR) to determine the BER of a communication link [2].

The proposed algorithm is generic network layer power management algorithm and does not use special functionality of any routing protocol. Therefore, it can be applied to any routing protocol. Different routing protocols such as Dynamic Source Routing (DSR) in reference [3], Any Path Routing without Loops (APRL), Ad hoc On-Demand Distance Vector (AODV), On-demand Multicast Routing Protocol (ODMRP) and System- and Traffic- dependent Adaptive Routing Algorithm (STARA) in reference [4] have been used by the authors to prove their concept. To demonstrate the performance and the capability of the proposed algorithm, we have applied it to Optimized Link-State Routing (OLSR) protocol as an example of a typical routing protocol.

In this paper, we will show that the proposed distributed power management algorithm adapts well in dynamic network topology and physical environment and provides a more reliable and strongly connected network. The related works in power control are listed in Section 2. Section 3 describes the proposed distributed power management algorithm. Propagation models are surveyed and the reasons for selecting log-distance path loss, log-normally distributed shadowing and rayleigh fading models are stated in Section 4. A brief description of OLSR protocol is presented in Section 5. Section 6 presents the simulation parameters and results and Section 7 concludes the paper.

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2. RELATED WORK

Power control algorithms in literature have been studied as techniques to improve network connectivity and energy efficiency. Most of the approaches studied are to find a complete set of transmission power for the nodes with the purpose to minimize the total power consumption [5] [6]. Because mobile ad hoc networks do not have any central scheduler, such centralized approaches are not applicable.

Another approach is to preserve network connectivity by assigning optimal transmit power for the nodes. Two distributed algorithms LINT and LILT are proposed in reference [7] which adjust transmission powers to maintain desired node connectivity. The algorithms, however, are reactive schemes and use Carrier Sense Multiple Access (CSMA), as a multiple access technique to evaluate their performance. COMPOW and CLUSTERPOW [5] [8] set the smallest power required to maintain each node's connectivity. These algorithms, however, find the smallest common power level at which the network is still connected. The problem with common power is that some nodes in the network could be in a highly dense area with very high connectivity and some might be in a low dense area even disconnected from the network.

Another approach is the Cone-Based Topology Control (CBTC) [9] where each node transmits with minimum power such that there is at least one neighbor in every cone of the angle centered at the node. In Minimum Spanning Tree (MST) based algorithm [10], each node builds its local MST independently and only keeps on-tree nodes that are one-hop away as its neighbor.

These power control algorithms do not adapt to the changes in environment and network topology.

3. DISTRIBUTED POWER MANAGEMENT ALGORITHM

We propose a dynamic distributed power management algorithm that optimizes node transmit power and minimizes inter-node interference in the network.

Consider a network of n nodes in an area A. If $P_i\ (t)$ and $\psi_i(t)$ represent the transmitting power and connectivity of node *i* in the network at time t, then select

$$P_i\ (t) \quad for\ node\ i\ \forall\ 1, 2, 3, \ldots, n$$

subject to the following constraints:

1. The node should have at least minimum connectivity, $\psi_{i_{min}}$, i.e. minimum acceptable number of neighbors with which the node has a bi-directional link with at any time t.

$$\psi_i(t) \geq \psi_{i_{min}}(t) \qquad for\ node\ i\ \forall\ 1, 2, 3, \ldots, n \tag{1}$$

2. For a packet from node *j* to node *i* to be correctly detected, SINR must be greater than a threshold, γ_{th}.

$$SINR_{ji}(t) = \frac{P_{ji}(t)}{P_{i0} + \sum_{k \in N, k \neq j} P_{ki}(t)} \geq \gamma_{th} \tag{2}$$

The node should not transmit at such a high level that it causes interference to other nodes in the neighborhood. Specifically, the algorithm will try to minimize the inter-node interference as shown in equation 3.

$$\min\left[P_{i0} + \sum_{\substack{k \in N \\ k \neq j}} P_{ki}(t)\right] \quad for\ node\ i\ \forall\ 1, 2, 3, \ldots, n \tag{3}$$

If a node has high node connectivity, then it can probably afford to decrease its power level and still maintain acceptable connectivity. Let $\psi_{i_{max}}(t)$ be the maximum number of neighbors allowed i.e. the upper acceptable connectivity threshold. This has an advantage of decreasing inter-node interference in the network.

$$\psi_i(t) \leq \psi_{i_{max}}(t) \qquad for\ node\ i\ \forall\ 1, 2, 3, \ldots, n \tag{4}$$

3. The transmit power for the nodes should be more than the minimum power level, $P_{i_{min}}$, but less than the maximum power level, $P_{i_{max}}$, defined by network and node power specifications.

$$P_{i_{min}} \leq P_i(t) \leq P_{i_{max}} \quad for\ node\ i\ \forall\ 1, 2, 3, \ldots, n \tag{5}$$

4. The algorithm also tries to conserve node's battery capacity, $C_i(t)$, which is one of the important design considerations for mobile ad hoc networks. The algorithm will only allow the nodes to increase their power level if their battery power is higher than the critical battery power level, $C_{i_{critical}}$.

$$C_i(t) \geq C_{i_{critical}} \qquad for\ node\ i\ \forall\ 1, 2, 3, \ldots, n \tag{6}$$

We assume that each node has no knowledge of other node's transmission power level. The algorithm is illustrated in a flowchart shown in figure 1.

Every node in the network continuously checks its connectivity, interference level and its battery capacity. We will assume that each transmitter has no knowledge of other node's power level.

If node *i* connectivity, ψ_i, is less than the minimum acceptable node connectivity, $\psi_{i_{min}}$, it will attempt to improve its connectivity by increasing power level. It can only increase its power level if its current power level, P_i, is lower than the maximum power level, $P_{i_{max}}$. It checks if there are any uni-directional links from other nodes. If there are, it will try to build bi-directional links with those potential neighbor nodes. It increases its P_i by an increment, α, and checks after a short time delay, τ_{short_delay}. If there are no uni-directional links to the node, then it should try to construct bi-directional links with other nodes which are not already its neighbors. The node can only create a uni-directional link by increase its P_i, so it's equality important for the potential neighbor to try to establish a link with it too. So, the node increases its P_i and sends out a *PowerLevelUp_Request* request. It then waits for medium time delay, τ_{medium_delay} to check if it managed to set up any new link. Since it is trying to construct link with nodes that are not its neighbors, the maximum hop count for *PowerLevelUp_Request* is set at 2. It should not be set too high because nodes transmitting at high power level can interfere nearby nodes. Thus, it will eventually select the lowest power level that will create bi-directional link.

Now if the node moves in to a dense area, it can probably afford to decrease its P_i and still maintain acceptable network connectivity. This has an advantage of reducing inter-node interference in the network. So, if ψ_i is higher than the upper connectivity threshold, $\psi_{i_{max}}$, it decreases its P_i and checks its ψ_i after τ_{short_delay}. It also decreases its P_i if its battery capacity, C_i, becomes less than the $C_{i_{critical}}$. It, thus, effectively selects the lowest P_i to keep the node well connected with at least $\psi_{i_{min}}$.

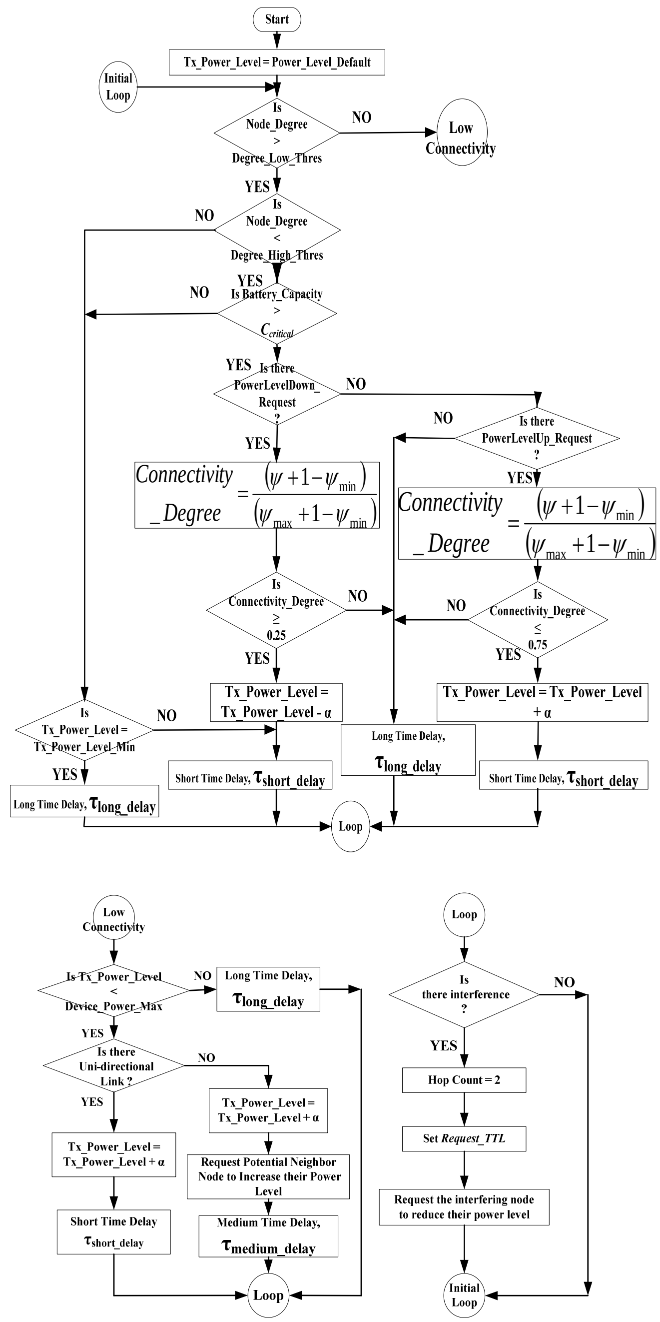

Figure 1- Flowchart of a dynamic co-operative power management algorithm

A node *i* will transmit *PowerLevelDown_Request* to other nodes if it is suffering from interference. It sets the maximum hop count for the request to 2 to prevent forwarding overhead. It also sets *Request_TTL* (Time To Live) so that older requests are ignored.

If a node receives a *PowerLevelDown_Request*, it will decrease its P_i if its ψ_i is in a higher acceptable range. If it changes its P_i, it checks its ψ_i after τ_{short_delay}. Otherwise, it waits for a long time delay, τ_{long_delay}, to avoid excessive calculations and overhead from frequent changes in P_i.

If a node *i* receives a *PowerLevelUp_Request*, it increases its P_i only if its ψ_i is in the lower acceptable range. It then waits for τ_{short_delay} to check its ψ_i.

A node will forward other node's requests if the hop count of the request is more than 1 and the *Request_TTL* is still valid.

If at any instance the node's C_i is not sufficient, i.e. less than $C_{i_{critical}}$, it will reduce its P_i to maintain minimum connectivity, $\psi_{i_{min}}$. The algorithm is in a sense greedy because achieving lowest connectivity is given the highest priority.

4. WIRELESS PROPAGATION MODEL

Propagation model estimates the average received signal at a given distance from a transmitting node in presence of propagating and fading losses. Most of the simulations done in mobile ad hoc networks employ either the trivial disk propagation model, the free space propagation model or the two-ray propagation model [11].

The disk propagation model does not take the physical channel into consideration. Free space propagation model considers a clear Line of Sight (LOS) path. The two-ray propagation model considers both the direct and a ground reflected propagation path between the source node and the destination node. It is, therefore, not suitable in case of mobile ad hoc networks where there are several multi-paths of similar strength and the propagation range is limited by the node transmission capability.

We will, therefore, use the log-distance path loss propagation model to model the propagation loss in mobile ad hoc wireless channel. The average path loss of the propagation signal in this model is expressed as a function of the distance and the path loss exponent, η, is given by equation 7 [11] [12]. (7)

Propagation environment dictates the value of η. η indicates the rate at which the path loss increases with distance.

This fading loss at a particular location due to shadowing effects is random and log-normally distributed as shown in equation 8 [13].

$$P_L(dB) = P_{PL}(dB) + X_\sigma$$
where,
X_σ: zero − mean random variable with standard deviation σ

(8)

Different versions of signal wave, because of reflecting objects and scatterers, combine in the receiving antenna to form a resultant signal that might widely vary in amplitude and phase, depending on the distribution of the intensity and relative propagation paths. The fading loss, P_{Fading}, used to model this small-scale fading and doppler effect due to multipath. In this paper, we will consider flat fading model which has a Rayleigh distribution probability density function (pdf) given by equation 9 [12],

$$p(r) = \begin{cases} (r/\sigma^2)\exp(-r^2/(2\sigma^2)) & (0 \le r \le \infty) \\ 0 \end{cases}$$

(9)

The Random Waypoint Mobility model (RWMM) [14] is used to model the node's mobility. In this mobility model, node selects a random destination within the roaming area and moves towards it at a speed between predefined minimal and maximum set value. After the node reaches destination, it stops for a predefined pause time and then randomly selects another destination and moves towards it. This node mobility behavior is repeated throughout the simulation.

The propagation model, therefore, determines the Signal to Noise Ratio (SNR) at the receiving node. We will model the multi-user network as interference-limited rather than noise-limited. Therefore, the Signal to Interference and Noise Ratio (SINR) given by equation 2 is used to determine the BER for a communication link [2].

The SINR or the BER determines the quality of the link and if the link can be selected for routing packets.

5. OPTIMIZATION LINK-STATE ROUTING PROTOCOL

OLSR optimizes the classic link state protocol by using only selected nodes called Multipoint Relay (MPR) to advertise links in the network [15]. Each node selects MPRs such that it has a bidirectional link to all of its two-hop neighbor nodes. Only MPRs are allowed to advertise the links by periodically broadcasting Topology Control (TC) messages. Neighbors, who are not selected as a MPR, receive and process the broadcast message but do not forward it. This technique of using MPR substantially reduces the message overhead.

The HELLO message maintains the local link and neighborhood information in the network and is used in selecting MPRs. The topology information from the HELLO and TC packets are used to construct routes in the network.

6. SIMULATION PARAMETERS AND RESULTS

The performance of power management algorithm is analyzed here through simulations carried out in OPNET network simulator [16].

The network consists of 100 nodes distributed over a 1000 meter by 1000 meter area. All the nodes are configured with OLSR and IEEE 802.11 MAC protocol. Each node, transmitting at 15dBm, always has packet of average size of 1024 bits to send. The simulation is conducted over urban area such as a city characterized by no LOS path but multiple versions of the signal due to many obstacles such as buildings and trees in the propagation path. We will model this environment by typical value for η of 3.2 and standard deviation of 4.0 dB. The node mobility is modeled with a minimum speed of 0 m/s and maximum speed of 3 m/s to simulate a pedestrian environment.

A link in this paper is defined as acceptable if the power of the signal in the receiving node is greater than the threshold value of -95 dBm in accordance with the 802.11 standard. All multi-user interference is treated as noise. If the power level of the signal in the receiving node falls below the threshold, the link is considered bad and is discarded. Only the good links are considered when routing the packets through the network.

The parameters of the power management algorithm: minimum and maximum connectivity, minimum and maximum power level and the time delays are all design considerations. We have conducted numerous simulations on this model over a wide range of these parameters. We have analyzed the impact of these parameters and its sensitivity on the network topology and performance.

However, to evaluate performance and capability of the algorithm in this paper, we have selected typical values for node connectivity of 6 and 8 for the lower threshold, $\Psi_{t_{min}}$, and upper threshold, $\Psi_{t_{max}}$. Similarly, the minimum and maximum transmission power levels, $P_{t_{min}}$ and $P_{t_{max}}$, are set at 5 mW and 100 mW. The node can select the power level between $P_{t_{min}}$ and $P_{t_{max}}$ at an increment, α, of 5 mW. The time delays: $\tau_{\text{short\_delay}}$, τ_{medium_delay}, and τ_{long_delay} are set to 5, 10 and 15 seconds. The initial transmission power level for all the nodes is set at 15dBm (approximately 30mW).

Node connectivity fluctuation of a typical node in the network over the period of simulation with and without power management algorithm is shown in figure 2. Without the power management algorithm, it is clearly seen that node connectivity initially increases to 20. It then steadily decreases as the node moves to a low node density area becoming totally disconnected from the network around 750 to 800 seconds. Throughout the simulation, node connectivity of a typical node in the network severely fluctuates even becoming disconnected from the network.

In case of power management algorithm, as node connectivity increases beyond the higher connectivity threshold, it decreases it's transmit power to approximately 5 mW clearly evident in figure 3. Similarly to earlier case, the node moves to an area with low node density and its node connectivity starts decreasing. The power management algorithm, however, realizes that node connectivity has decreased below the lower connectivity threshold and starts increasing it power level to 100 mW. The node with the power management algorithm does not even get disconnected from the network at any point during the simulation. It is clear from figure 2 and 3 that node adjusts its power level between 5 mW to 100 mW to maintain acceptable network topology.

Figure 2 and 3 highlight the variation in routing parameter because of changes in environment and the network. Nodes in the network should adapt to variations in the environment and the network to provide strongly connected and more reliable network thereby improving routing performance.

The distribution of node connectivity of all the nodes in the network with and without power management algorithm is shown in figure 4. Connectivity of node without power management algorithm was found to be distributed from 0 to 25 with more than 2% of the node totally disconnected. However with power management algorithm, approximately 46% of the nodes have acceptable connectivity with less than 0.1% of the nodes totally disconnected from the network at any time during the simulation. Figure 5 shows the distribution of transmit power level of the nodes in the network. 57% of the nodes have its power level less than the initial power level of 15 dBm with 7% of the node at the highest power level of 100 mW.

It is clear from figure 2 that routing protocol with power management algorithm reduces node connectivity and topology fluctuations and therefore decreases routing overhead as evident in figure 6.

Further, in the work presented in reference [17] we have shown that under similar simulation environment the algorithm increases the network throughput by as much as 37%. The algorithm was also found to increase average node power from 15dBm to 19.37dBm. This intuitively implies an increase in inter-node interference. However, the average noise interference was found to decrease by about 2dBm with this algorithm even though the average node power increased by 4.37dBm. This is because the power management algorithm keeps a check on inter-node interference by not letting the nodes increase their power indiscriminately.

7. CONCLUSION

We have shown that the proposed distributed power management algorithm adaptively preserves network connectivity, increases network performance and reduces interference with the dynamic environment and network topology. The proposed algorithm is generic network layer power management algorithm and can be applied to any routing algorithm. To demonstrate its performance and capabilities, we have applied it to OLSR as an example of a typical routing protocol. It does not utilize any functionality specific to a particular protocol such as OLSR in this case.

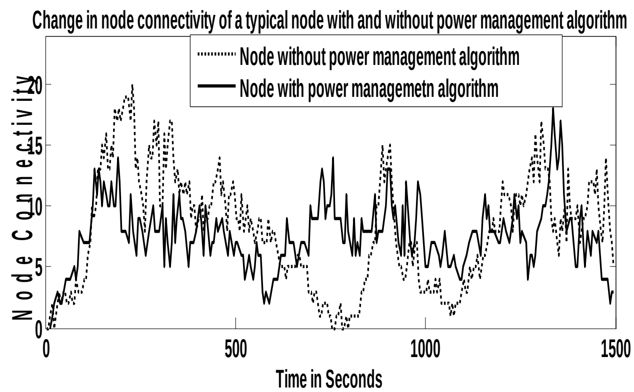

Figure 2- Change in node connectivity of a typical node in the network with and without power management algorithm

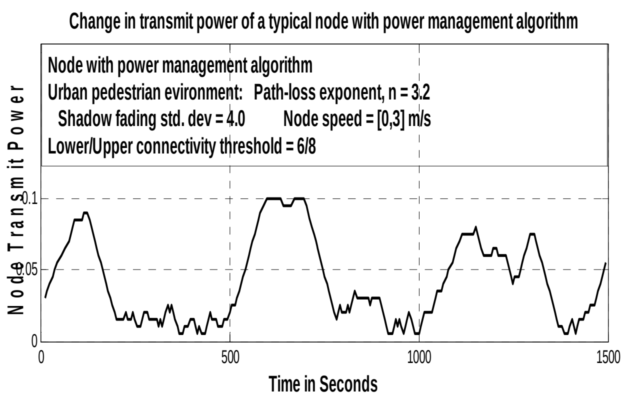

Figure 3- Change in transmit power of a typical node with power management algorithm

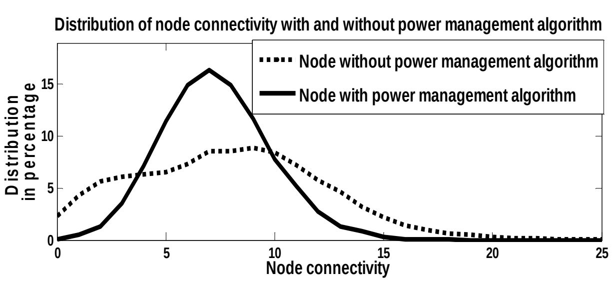

Figure 4- Distribution of node connectivity of all the nodes in the network with and without power management algorithm

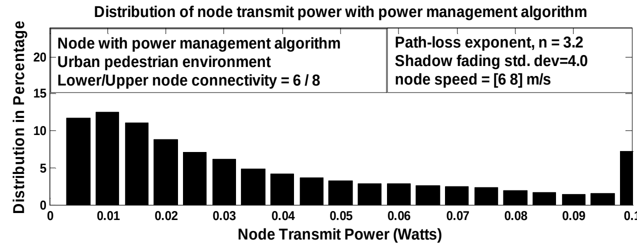

Figure 5- Distribution of node transmit power of all the nodes in the network with power management algorithm

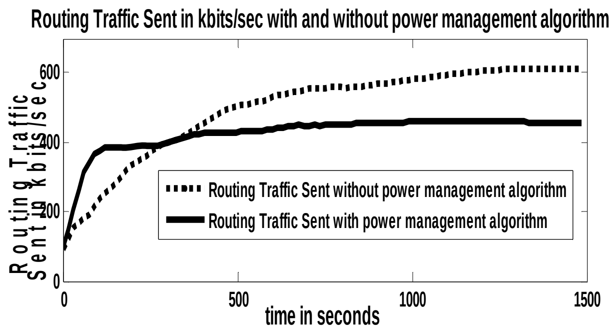

Figure 6- Average total routing traffic sent with and without the power management algorithm

It is clear from figure 2 that node connectivity of a typical node in the network severely fluctuates from 0 to 20 even becoming disconnected from the network for a significant period of time during the simulation. Figure 2 and figure 3 show that the network adapts better to the changes in the physical environment and network topology with the power management algorithm. It reduces node connectivity fluctuations even preventing node, to a certain extent, from being totally disconnected from the network. Thus the proposed algorithm provides strongly connected and more reliable network. It also lowers inter-node interference and routing overhead consequently increasing network performance.

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